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MULTI-AGENT REMOTE CONTROL SYSTEM FOR EXTINGUISHING FOREST FIRES WITH HETEROGENEOUS ELEMENTS OF A ROBOTIC COMPLEX

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ABSTRACT

Scientific tasks of the research are: development and justification of the composition of the robotic light class complex for extinguishing forest fires; development and justification of the composition of a unified human-machine interface based on poly-joysticks and a video mask for controlling elements of a robotic complex; development and justification of the structure of a multi-agent remote control system. The tasks were solved by methods of experimental modeling and theoretical analysis of the obtained results. As a result of research, the following new results were obtained: a new composition of a robotic complex for extinguishing forest fires was developed; a unified human-machine interface based on optical ministicks for controlling elements of a robotic complex with differentiated functionality was developed; the structure of a multi-agent remote control system was developed, built on a hierarchical principle with the ability to control the operation of robot operators at two levels of control. The use of a robotic complex will improve the efficiency of extinguishing forest fires, significantly reduce the risks of death and injuries of rescue units' personnel, and reduce the cost of extinguishing a fire.

KEYWORDS: Forest Fire, Fire Extinguishing, Robotic Complex, Multi-Agent Remote Control System & Human-Machine Interface

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Original Article

1. INTRODUCTION

The protection from forest fires is a dangerous, time-consuming and costly event. Every year, 200 thousand forest fires occur on the planet (Ministry of Civil Defense, n/d). According to Greenpeace, the world average annual forest loss is about 1.47 million hectares or 0.5 percent of its area (Greenpressa, n/d). Economic damage from fires in the United States is at least $ 25,000 per hectare of a forest. In Russia, according to Federal Forestry Agency Rosleskhoz, this figure is 1.2–1.5 thousand dollars per hectare (Nature of Russia, n/d).

To reduce the risk of occurrence and spread of forest fires, a complex of preventive measures is being developed, aimed at both preventing fires and fighting and non-spreading fire over large areas. There are a large number of technologies and technical means for extinguishing forest fires; however, an effective means of extinguishing forest fires does not yet exist. In this regard, there is a need to develop new, more efficient ways and means of extinguishing fires (Amano, 2002).

Tenzosensor Company with the support of the state in the person of the Ministry of Science and Higher Education of the Russian Federation is developing a robotic complex to extinguish forest fires (Nikitin*et al*, 2019; Golubin*et al*., 2018a).

Problems of extinguishing forest fires are relevant to more than 70% of countries (Keane*et al.,* 2008; Stephens, 2005). The most effective and safe means of extinguishing fires are robotic complexes for fire extinguishing (Zinko*et al.,* 2011).

There are various remote-controlled technical means for extinguishing forest fires with a range of control from 200 to 1000 m. For example, the fire robot "Thermite RS1-T2" of the company "Howe and Howe Technologies" is equipped with a remote control with a range of up to 400 m (Thermite Fire Fighting, n/d). The InRob firefighting robot FFR-1 can be remotely controlled by the operator from the distance up to 260 m (Fai Tanand Dhar Malingam, 2013), and the LUF-60 mobile fire extinguishing system by RECHNERS Löschsysteme GES. M. B. H is controlled within the operator's direct line of sight at distances of up to 300 m (Mobile Firefighting…, n/d). Mobile robotic reconnaissance and fire-fighting complex MRK-RP, developed by the Research Institute of Special Mechanical Engineering of N. E. Bauman Moscow State Technical University and FGU VNIIPO EMERCOM of Russia, can be controlled by the operator over the radio in conditions of direct visibility up to 1000 m (Fire Robot at Interpolitech, 2015).

The use of remote control technologies allows to eliminate the presence of people in the hazardous area of work, reduce the danger and laboriousness of extinguishing forest fires due to its robotization (Korchak, *et al.,* 2013).

Currently, distributed mobile robotic systems - groups of mobile robots that jointly solve a common task, are becoming increasingly relevant (Petrov*et al.,* 2016; Szántó*et al.,* 2014). This is due to the fact that the functionality of an individual robot is significantly limited by its functionality and operational range. Therefore, to solve complex problems, such as, for example, extinguishing forest fires, it is advisable to use distributed robotic systems, which include robots with different functional capabilities. The advantages of using robots in groups are obvious: a longer range, extended functionality of the complex as a whole, a higher probability of completing the task, achieved due to the possibility of redistributing some tasks between robots in case of failure of some of them (Derbas*et al.,* 2014).

When building a distributed robotic system, the most important and challenging task is to develop a control system for the group as a whole (Shepardand Kitts, 2018; Rossi*et al.,* 2017).

The system of centralized management of a group of robots should be a single point of control, precluding the use of specialized remote controls, adapted to control different robots. The control should be carried out with the help of unified human-machine interfaces with many degrees of freedom, allowing high-quality control of various equipments (Golubin et al., 2018b). The remote control system, built on a hierarchical principle, should provide the possibility of multi-level control of the operation of robot operators, control processes and communication (Ma*et al.,* 2017).

The robotic complex for extinguishing forest fires (Nikitin*et al.,* 2019b; Andrianov*et al.,* 2019), developed by Tenzosensor, includes (figure 1):

- Fire robot to directly extinguish flame breaks along the edge of the fire, as well as start of annealing from the support strip;
- Robotic trencher for laying protective and supporting mineralized strips;
- Robotic mini-harvester for creating firebreaks by felling of dry trees;
- Drone for reconnaissance and surveillance;
- Mobile control station on the basis of off-road vehicles equipped with trailers for the transport of robots.

The multi-agent remote control system of the robotic complex is based on the computing resources of the mobile control station.

The unit that manages the robots of the complex consists of a foreman, a supervisor and three robot operators located in three machines that form a mobile control center.

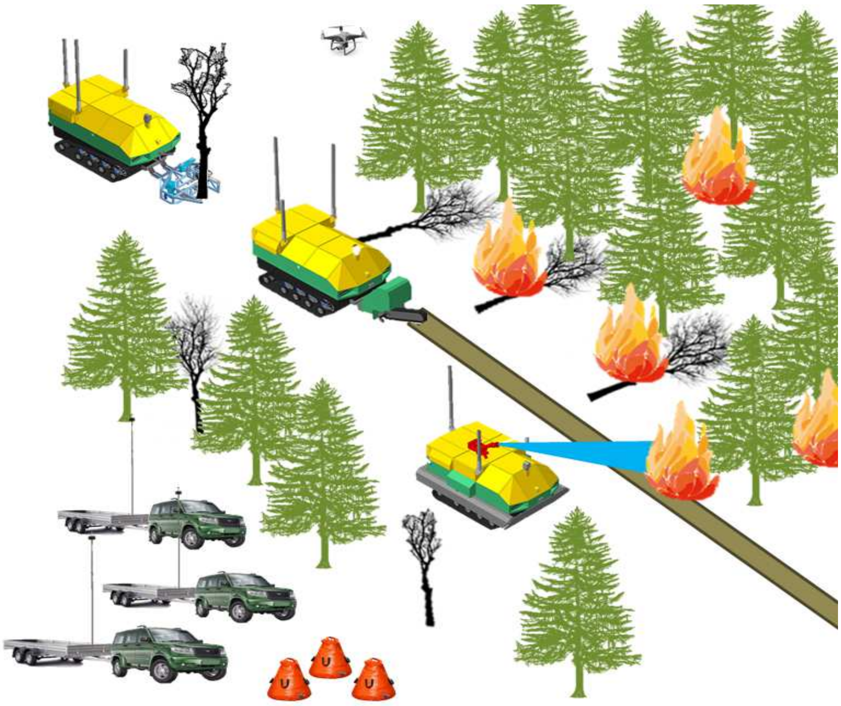

Figure 1: Robotic Complex for Extinguishing Forest Fires.

2. METHODOLOGY

Justification of the Structure of Multi-Agent Remote Control System

The multi-agent remote control system (MSDU) is designed to provide processes for direct remote control of operators by the operation of robots. The system is hierarchical and is built on a modular basis.

The overall management of the work and setting of tasks is carried out by the foreman. Using the drone, the supervisor monitors the work of the complex, as well as reconnaissance in order to identify the situation in the emergency zone. If necessary, the supervisor can perform the functions of a foreman from his workplace.

Operators control the movement and operation of special equipment of elements of the robotic complex. Control over the work of operators is carried out at two levels of control: by the foreman and by the supervisor. If necessary, the foreman or supervisor can take control of any robot.

The developed multi-agent remote control system is distinguished by a substantial distribution of control algorithms, since the control logic is implemented in the form of software components operating in parallel in real-time and placed on computers located in space. Moreover, it is important to note that each software component has a certain degree of autonomy.

Multifunctional poly-joysticks (NikitinandBelov, 2013) of a unified human-machine interface are used as input devices for the user interface of the system, which allow combining control efficiency, multi-tasking mode and excellent

ergonomics. There is also a duplicate channel for entering information in the form of classic devices - a mouse and a keyboard.

As an output device, a video mask is used, which provides reliable protection of the operator's head against various influences and comfort during operation. The video mask is equipped with headphones and a microphone for voice communication. Additionally, each control machine has duplicate output channels in the form of ceiling video monitors installed at each workplace.

The MSDU user interface windows are designed in such a way as to ensure the prompt display of the currently important information, and have the ability to adapt to the changing operational tactical situation.

In the division that carries out activities to extinguish a forest fire, the task manager is the only person - the foreman. Therefore, to implement the interaction between the participants of the division, a centralized model was chosen. The basis of the multi-agent remote control system is a server application providing the collection, storage and transmission of information. Each client sends its own data to the server that other clients can read from the server. The client-server model allows increasing the reliability of the system as a whole. The interaction scheme is shown in Figure 2.

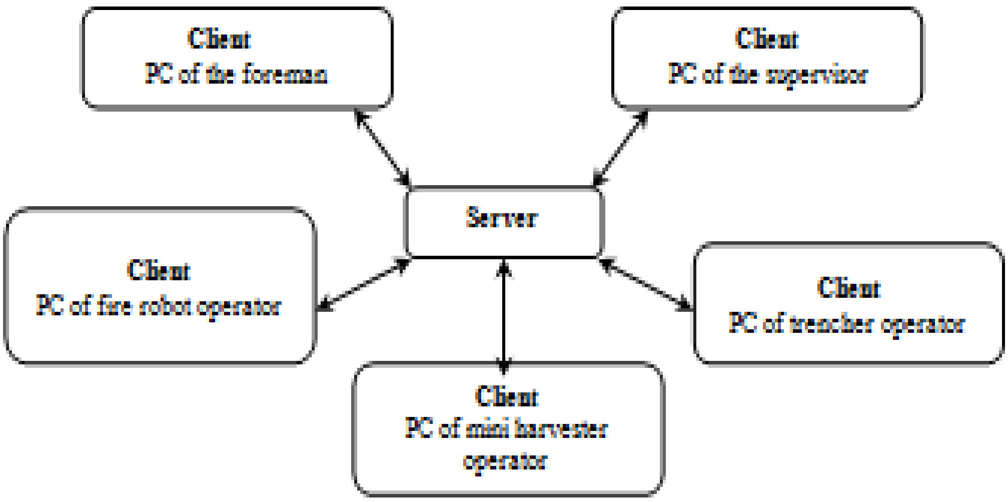

Figure 2: The structure of the Interrelations of Multi-Agent Remote Control System.

Conflict-free work of workplaces of robot operators is provided by the client-server architecture of a multi-agent remote control system in which tasks and network load are distributed between service providers and customers. In addition, for communication with robots, operators use individual frequency communication channels, which exclude their conflicts due to the use of multi-channel data transmission systems.

3. RESULTS

In accordance with the task, the specialists of Tenzosensor developed a multi-agent remote control system of a robotic complex for extinguishing forest fires. The system is built on a hierarchical principle and provides control of the operation of robot operators at two levels of control: by a supervisor and by a foreman.

A block diagram of a multi-agent remote control system is presented in figure 3.

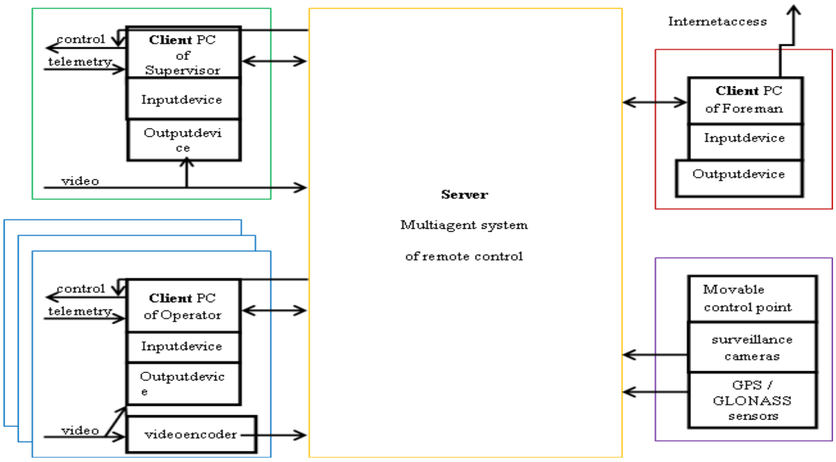

Figure 3: Block Diagram of Multi-Agent Remote Control System.

The multi-agent remote control system of the robotic complex is based on the computing resources of the mobile control station (hereinafter referred to as MCS), which consists of three cross-country vehicles UAZ Patriot with the necessary equipment.

Components of MCS Vehicle

In total, the MCS has three workplaces for robot operators, a workplace for the supervisor and a workplace for the foreman. In addition to the workplaces of personnel and sources of autonomous power supply, each MCS vehicle has the following set of components:

- Reversing IP camera on the roof of the car, providing all-round visibility;
- IP camera in the car;
- a switch for connecting all devices of the car into a local network;
- a Wi-Fi router for uniting all cars into a single network;
- GPS / GLONASS location module, connected to one of the car’s computers.

In the first car, there are workplaces of a foreman and a supervisor. All MCS workplaces are equipped with sets of a unified human-machine interface, allowing you to conveniently control all elements of the robotic complex. If necessary, the foreman and supervisor can intercept the control of robots. Special equipment allows the supervisor to control the surveillance and reconnaissance drone from his workplace. The video signal from the drone goes to the server, which, if necessary, provides all users with access to the digital video stream via the local network. Another additional equipment of the car is an Internet modem that provides connection of the foreman’s PC to the Internet.

In the second car, there is the workplace of the fire robot operator. A car trailer is fitted with a transceiver for sending control commands and receiving telemetry data, as well as a receiver for receiving video signals from a fire robot. The video signal in analog form enters the video coder, which performs its conversion into digital form and provides access to the digital video stream via a local network. The operator receives the video signal directly, with minimal delay.

In the third MCS vehicle, the workplaces of the operator of the robotic trencher and the operator of the robotic mini-harvester (felling machine) are located. In the cars trailers there are transceivers of control commands and telemetry, as well as receivers for receiving video signals from robots. Video encoders are designed to process analog video signals from robots and convert them to digital form. Robot operators receive video signals directly, with minimal latency.

The Wi-Fi network is used to connect the local networks of MCS cars. Radio channels at frequencies of 230 and 1200 MHz are used for direct control of robots. Local networks of cars and Wi-Fi network provide the necessary speed of connection of workplaces at MCS. The use of Wi-Fi provides a sufficient radius of stable communication between the MCS cars, and the radio channels of communication with robots provide the required range of information transmission over the radio channel - not less than 2000 m in open terrain conditions, which is superior to existing analogues.

Opportunities for Staff due to Unification of all MCS Vehicles

The unification of all MCS vehicles into a common network through Wi-Fi routers provides the following opportunities for staff:

- text messaging;
- the foreman and supervisor have an opportunity to receive video streams from all cameras of the elements of the robotic complex, and for operators it's a video stream from the drone camera of intelligence and surveillance;
- Opportunity for the foreman or supervisor to take control of any robot.

Operators control robots directly from their PCs. Communication between the robot and the operator is carried out via wireless channels (the connection topology is “point-to-point”). Communication channels of robots operate independently of each other. On the local network, operators exchange data with the MSDU server containing tasks assigned by the foreman, operator responses, control interception commands, telemetric information on the state of the complex's elements, etc. If necessary, operators can receive a video stream from a surveillance and reconnaissance drone camera. In case of interception of control by a foreman or supervisor, the operator’s computer functions as a bridge between the robot and the computer that intercepts the control.

The foreman sets the tasks for the staff and coordinates the work of operators and the supervisor. He can view three video streams simultaneously from various sources in real time (robots video cameras, drone, video cameras of MCS cars). If necessary, the foreman can take control of one of the robots, while the interface of the foreman's window is changed to the operator's one.

The supervisor monitors the work of operators, viewing video streams from various sources in real time (video cameras of robots, drone, video cameras of MCS cars), and also controls the drone, monitoring the situation with the help of drone’s camera and carrying out intelligence. If necessary, the supervisor can take control of one of the robots, as well as replace the foreman.

4. CONCLUSIONS AND RECOMMENDATIONS

The proposed multi-agent remote control system allows:

- To provide high-quality, controlled at two levels of control, management of a group of dissimilar robots and drone surveillance and reconnaissance.
- To provide control of telemetry, operations performed and interception of control of any robot from the workplace of the foreman and supervisor in case of emergency situations.
- To create opportunities for a clear and well-coordinated teamwork of a complicated robotic complex for extinguishing forest fires, consisting of three dissimilar robots and a surveillance and reconnaissance drone.

- To take advantage of the latest unified human-machine interface based on poly-joysticks and a video mask to control the elements of a robotic complex with differentiated functionality.

The development of a multi-agent remote control system will further create a promising remote control system for a robotic fire extinguishing complex, which can be controlled via the Internet from anywhere in the world.

Preliminary studies show the feasibility of using such hierarchical systems to control groups and teams consisting of robots and controlled devices for various purposes, as they increase the controllability of complex robots.

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REFERENCES

1. *Ministry of Civil Defense, Emergencies and Elimination of Consequences of Natural Disasters (EMERCOM of Russia). Retrieved from: http://www.mchs.gov.ru (Accessed on June 3 2019).*
2. *Nature of Russia: national portal. Retrieved from: http://www.priroda.ru (Accessed on June 6 2019).*
3. *Greenpressa: Forestry Forum. Retrieved from: http://www.greenpressa.ru (Accessed on May20 2019).*
4. *Amano, H. (2002). Present Status and Problems of Fire Fighting Robots. SICE 2002.Proceedings of the 41st SICE Annual Conference, 2, 880–885.*
5. *Nikitin, V. S., Golubin, S. A., Belov, R. B., Andrianov, N. V. and Shurtakov, V. V. (2019). Multiagent robotic system application in conditions of forest firefighting. International Journal of Civil Engineering & Technology, 10(2), 144–151.*
6. *Keane, R. E. Agee, J. K., Fulé, P., Keeley, J. E., Key, C., Kitchen, S. G., Miller, R. and Schulte, L. A. (2008). Ecological effects of large fires on US landscapes: benefit or catastrophe? International Journal of Wildland Fire, 17(6), 696–712.*
7. *Stephens, S. L.(2005). Forest fire causes and extent on United States Forest Service lands. International Journal of Wildland Fire, 14,213–222.*
8. *Zinko, R., Jemeļjanovs, V. and Malahova, J. (2011). Usage of Robots for the Increasing the Effectiveness of the Fire Protection. Safety of Technogenic Environment, 1, 74–80.*
9. *Tuzon–Guarin, J. M. (2016). Housekeeping Management Practices and Standards of Selected Hotels and Restaurants of Ilocos SUR, Philippines. International Journal of Business Management & Research (IJBMR) ISSN (P), 2249-6920.*
10. *Thermite Fire Fighting Robot Site. Thermite RS1-T3 AND RS2-T2 etrieved from: http://www.roboticfirefighters.com. (Accessed on June 10 2019).*
11. *Fai Tan, Ch. and Dhar Malingam, S. (2013). Fire Fighting Mobile Robot: State of the Art and Recent Development. Australian Journal of Basic and Applied Sciences, 7(10), 220–230.*
12. *Mobile Firefighting Supporting Machine LUF60 Hong Kong Fire Services Department. Retrieved from: https://www.hkfsd ov.hk/eng/gallery/equip/fire/c_luf60.html (Accessed on May 232019).*

13. *Fire Robot at Interpolitech.(2015). International exhibition of state security equipment INTERPOLITEX. Retrieved from: http://www.interpolitex.ru/media/news/ novosti-vystavki/pozharnyy-robot-na-interpolitekh-2015/ (Accessed on May 30 2019).*

14. *Korchak, V. Yu., Rubtsov, I. V, Ryabov, A. V. (2013). State and development prospects of ground-based military and special-purpose robotic complexes. Engineering Journal: Science and Innovation, 3, 1–10.*

15. *Petrov, V. F, Terentev, A. I., Simonov, S. B., Korolkov, D. N., Komchenkov, V. I. and Arkhipkin, A. V. (2016). Problems of Group Control of Robots in the Robotic Complex of Fire Extinguishing. SPIIRAS Proceedings, 45, 116–129.*

16. *Szántó, Z., Márton, L. and György, S. (2014). Teleoperated mobile robot groups with reconfigurable formation. IEEE International Conference on Autonomous Robot Systems and Competitions (ICARSC), 235–240.*

17. *Hussein, O. A., & Rao, P. R. (2016). Fault Location and Isolation using Multi Agent Systems in 16 Buses Distribution System. International Journal of Electrical and Electronics Engineering Research, 6, 21–38.*

18. *Derbas, A. M., Al-Aubidy, K. M., Ali, M. M. and Al-Mutairi, A. W. (2014). Multi-robot system for real-time sensing and monitoring. 15th International Workshop on Research and Education in Mechatronics (REM), 1–6.*

19. *Shepard, J. T. and Kitts, C. A. (2018). A Multirobot Control Architecture for Collaborative Missions Comprised of Tightly Coupled, Interconnected Tasks. IEEE Systems Journal, 12(2), 1435–1446.*

20. *Rossi, A., Staffa, M. and Rossi, S. (2017). Supervisory Control of Multiple Robots through Group Communication. IEEE Transactions on Cognitive and Developmental Systems, 9(1), 56–67.*

21. *Golubin, S., Nikitin, V., Belov, R.(2018). The Use of LED-Based Digital Optical Ministicks as Multi-Functional Controls for Unified Human-Machine Interfaces. Light&Engineering, 26(3), 188–193.*

22. *Ma, H. Hönig, W. Cohen, L., Uras, T. Xu, H. Satish Kumar, T. K., Ayanian, N. and Koenig, S. (2017). Overview: A Hierarchical Framework for Plan Generation and Execution in Multirobot Systems. IEEE Intelligent Systems, 32(6), 6–12.*

23. *Nikitin, V., Golubin, S., Belov, R., Gusev, V. and Andrianov, N. (2019). Development of a robotic vehicle complex for wildfire-fighting by means of fire-protection roll screens. IOP Conf. Series: EarthandEnvironmentalScience, 226,012003.*

24. *Andrianov, N., Belov, R., Nikitin, V. et al. (2019). The method of extinguishing forest fires and a robotic complex for its implementation. Patent of Russia No. 2677413. Bulletin No. 2.*

25. *Ministry of Science and Higher Education of the Russian Federation. Federal target program "Research and development in priority areas of development of the scientific and technological complex of Russia for 2014-2020." Retrieved from: http://fcpir.ru. (Accessed on June 13 2019).*